Watch Peripheral Arterial Tonometry in the Diagnosis of Pediatric Obstructive Sleep Apnea

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Abstract
Objective. To assess the accuracy and clinical reliability of watch peripheral arterial tonometry (PAT) compared with polysomnography (PSG) for the diagnosis of pediatric obstructive sleep apnea (OSA).

Study Design. Prospective, diagnostic test study.

Setting. National tertiary referral hospital.

Subjects and Methods. Patients aged 8 to 15 years with clinically suspected OSA were recruited. All participants underwent PSG and PAT simultaneously in the sleep laboratory.

Results. Thirty-six patients were included, with a mean age of 10.2 ± 1.8 years. Median (interquartile range) of the apnea hypopnea index (AHI) was 8.0 (5.5-12) and 2.9 (0.5-7.5) events/h, median oxygen desaturation index (ODI) was 2.5 (1.4-8.3) and 1.3 (0.2-3.8) events/h, mean ± standard deviation total sleep time was 398.4 ± 38.3 and 401.9 ± 36.1 minutes, and mean minimum oxygen saturation was 87.1% ± 8.1% and 89.4% ± 7.1% for PSG and PAT sleep parameter results, respectively. Agreement between methods was excellent for the AHI (intraclass correlation coefficient [ICC]: 0.89; 95% CI, 0.40-0.96; P < .001) and ODI (ICC: 0.87; 95% CI, 0.69-0.94; P < .001). Correlation between methods was very good for the ODI (r = 0.83; 95% CI, 0.67-0.90; P < .001) and moderate for the AHI (r = 0.64; 95% CI, 0.30-0.85; P < .001). From the receiver operating characteristic curve constructed to assess PAT diagnostic capability, AHI of PAT (W-AHI) at a cutoff of 3.5 events/h provided the highest accuracy (76.9% sensitivity, 78.3% specificity), while W-AHI at 10 events/h yielded 91.3% specificity for diagnosing severe OSA.

Conclusion. PAT correlated well and had good agreement with PSG. Children with W-AHI ≥10 had high specificity for the diagnosis of severe OSA. Larger studies with PAT designed for children across all age ranges and with a normal control group are still needed.

Keywords
obstructive sleep apnea, pediatric, polysomnography, peripheral arterial tonometry, Thailand, WatchPAT, home sleep test, HST

Published online: 2018 August 27; revised January 8, 2018; accepted March 12, 2018.

Sleep-disordered breathing in children includes groups of abnormalities ranging from primary snoring to obstructive sleep apnea (OSA) characterized by partial or complete obstruction of the upper respiratory tract during sleep, which results in hypoxia and hypercapnia or repetitive episodes of arousal to reestablish the airway.1 OSA is estimated to affect about 1.2% to 5.7% of the pediatric population in the United States2 and about 0.7% to 1.3% of children in Thailand.3 It not only adversely affects quality of life but also can lead to several health consequences, including cardiovascular abnormalities and neurocognitive dysfunction. Early detection and timely diagnosis of OSA are, therefore, essential so that appropriate management can prevent these potential adverse outcomes.

Although polysomnography (PSG), which involves comprehensive recording of physiologic variables, is the generally accepted gold-standard test for diagnosis of OSA,4-7 it is often associated with disadvantages, including patient discomfort, high cost, long waiting list, and the need for technical expertise to monitor the process and to score the results. In cases or settings where PSG is not available, the American Academy of Pediatrics (AAP) recommends that physicians perform alternative tests in uncomplicated cases.

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This article was presented at the 2017 AAO-HNSF Annual Meeting and OTO Experience; September 10-13, 2017; Chicago, Illinois.

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of OSA. Several technologies that have recently been developed to facilitate the ambulatory diagnosis of OSA have yielded impressive results compared with the results of PSG.8-12 Watch peripheral arterial tonometry (PAT) is a portable wrist-worn OSA diagnostic device that incorporates actigraphy to differentiate between wake and sleep stages and a PAT signal probe that measures arterial volume change in the fingertip that corresponds with sympathetic activation. Herscovici et al13 reported a good relationship between sympathetic activation and rapid eye movement (REM) sleep stage, and they created an automatic computerized algorithm to characterize that association. The notable features of PAT are its simplicity, convenience, and ability to measure sleep parameters, including the apnea hypopnea index (AHI), respiratory disturbance index (RDI), total sleep time (TST), and sleep stages—all of which were reported to have a strong correlation with the same parameters as measured by PSG in adult patients.14-21 However, data specific to the application of PAT for diagnosing pediatric OSA are scarce. Accordingly, the aim of this study was to investigate the accuracy and clinical reliability of the PAT compared with PSG for the diagnosis of OSA in children.

**Methods**

**Study Design**

This prospective, diagnostic test study was conducted at the Department of Otorhinolaryngology, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand, during the January 2016 to October 2016 study period. Siriraj Hospital is Thailand’s largest national tertiary referral center. All participants were consecutively recruited and scheduled for PSG according to indications set forth in the clinical practice guideline.7 Written informed consent was obtained from all caregivers, and assent was obtained from all minor-aged participants prior to their participation in the study. The protocol for this study was approved by the Siriraj Institutional Review Board (Si 517/2015).

**Study Population**

Patients aged 8 to 15 years with clinically suspected OSA (documented history of labored snoring, witnessed apnea, struggling, and/or gasping during sleep) who were referred to the Department of Otorhinolaryngology, Faculty of Medicine Siriraj Hospital were included. Patients having any 1 or more of the following were excluded: comorbidities including craniofacial anomalies, neurological diseases, cardiovascular diseases, peripheral arterial diseases, finger anomalies, use of α-blocker drugs, and/or incomplete PSG or PAT data.

Since no previous study could be identified in the English language literature relating to PAT in pediatric patients, the sample size was calculated by using the intra-class correlation coefficient (ICC), which represented agreement between PAT and PSG from studies in adults by Pittman et al16 and Ceylan et al.18 The average ICC was 0.9 with an allowable error of 0.08, and the 2-sided confidence interval was set at 95%. The calculation yielded a minimum sample size of 33 patients. In order to compensate for an estimated potential dropout rate (for any reason) of 10%, 7 patients were added for a final total of 40 patients.

**Intervention**

All participants underwent simultaneous full-night level 1 PSG and PAT testing in our center’s sleep laboratory. The room temperature was adjusted according to patient preference, with 24°C to 25°C being the most often preferred temperature. This condition is within the recommended operational temperature for PAT according to the instruction manual (0-40°C).22 Information regarding history and physical examination was obtained from patient medical records. PSG (Somte PSG, Compumedics Ltd, Victoria, Australia) was used to record sleep parameters, including electroencephalogram (EEG), electrooculogram (EOG), chin and leg electromyogram (EMG), electrocardiogram (ECG), airflow signals, respiratory effort signals, oxygen saturation, and body position (Figure 1). PSG data were scored and interpreted by sleep specialists who were blinded to PAT results using criteria set forth by the American Association of Sleep Medicine (AASM) in 2016.23 PAT (WatchPAT 200; Itamar Medical Ltd, Caesarea, Israel) with integrated actigraphy technology was worn around the wrist. Two finger probes extended from the device. One was a PAT probe for detecting the PAT signal...
from the index finger, and the other was a pulse oximetry probe for measuring arterial oxygen saturation from the ring finger of the nondominant hand, according to the instruction manual (Figure 2). PAT continuously recorded parameters, including PAT (signal and amplitude), pulse rate, oxygen saturation, actigraphy, snoring, and body position. PAT data were analyzed by an automated computerized algorithm coded into Itamar’s ZZZPAT software program (version 4.3.61.4).

Outcome Measurement

Four parameters (AHI, oxygen desaturation index [ODI], total sleep time [TST], and minimum oxygen saturation [MinO₂sat]) were compared between PSG and PAT to determine the accuracy and diagnostic capability of PAT for diagnosis of pediatric OSA. AHI during non-REM (NREM) and REM sleep was also compared between PSG and PAT.

Statistical Analysis

All statistical analyses were performed using SPSS Statistics version 18 (SPSS, Inc, an IBM Company, Chicago, Illinois). Categorical data are presented as number and percentage. Continuous data are shown as mean ± standard deviation (SD) for parametric variables and median and interquartile range (IQR) for nonparametric variables. Agreement between PAT and PSG was determined using the correlation coefficient (r) as follows: Pearson correlation coefficient analysis for parametric data and Spearman rank correlation coefficient analysis for nonparametric data. Correlation was categorized as follows: little or none (0-0.24), fair (0.25-0.49), moderate to good (0.50-0.74), and very good to excellent (0.75-1.00). Linear regression analysis was performed to identify the equation that characterizes the relationship between the AHI obtained from PAT (W-AHI) and the AHI obtained from PSG (P-AHI). Since no previous data in pediatric patients were available, receiver operating characteristic (ROC) curves were constructed to identify W-AHI cutoff points (ie, sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], and accuracy) to determine the diagnostic capability of PAT for diagnosing pediatric OSA. A P value of less than .05 was considered statistically significant.

Results

We consecutively recruited 40 patients aged 8 to 15 years with clinically suspected OSA who met the selection criteria starting from January to October 2016. Four patients were excluded for the following reasons: incomplete PSG data (1 patient) and incomplete PAT data (3 patients). The remaining 36 patients were included in the final analysis. The mean age of patients was 10.2 ± 1.8 years. Baseline demographic, nutritional status, and clinical characteristics of patients are shown in Table 1. Using P-AHI criteria, 6 patients (16.7%) were diagnosed with mild OSA, 17 (47.2%) with moderate OSA, and 13 (36.1%) with severe OSA (Figure 3).

Sleep parameters obtained from PSG and PAT are shown in Table 2. Agreement between PAT and PSG was excellent for the AHI (ICC = 0.89) and ODI (ICC = 0.87) (Table 3). Correlation between PAT and PSG was very good to excellent for the ODI (r = 0.83) and moderate to good for the AHI (r = 0.64) (Table 4). More details are presented in Tables 3 and 4.

Scatterplot of PSG vs PAT for AHI is presented in Figure 4. Linear regression analysis was used to create the equation representing the relationship between W-AHI and P-AHI. The final equation was P-AHI = 1.09 (W-AHI) + 3.95 (P < .001).

ROC curve analysis was used to evaluate the diagnostic capability of PAT. Given that no previous studies reported the threshold value of W-AHI cutoff points in pediatric patients and that there were no children without OSA (AHI < 1) in this study, P-AHI values of 5 and 10 events per hour (which is the cutoff value for diagnosing moderate and severe OSA, respectively) were used to create the ROC curve. Only the ROC curve for P-AHI of 10 events per hour was shown to be statistically significant, with an area under the curve (AUC) of 0.82 (95% CI, 0.67-0.98; P < .001) (Figure 5). According to this curve, a W-AHI cutoff point of 3.5 provided the highest accuracy at 77.8%, with a sensitivity of 76.9% and a specificity of 78.3% for diagnosing severe OSA (P-AHI ≥ 10). When using a W-AHI cutoff...
point of 10, the specificity was 91.3% for differentiating severe OSA from mild and moderate OSA (Table 5).

**Discussion**

In adult OSA, PAT may provide sleep parameter data similar to that of PSG but with slightly higher values than those obtained from PSG. In contrast, among the pediatric subjects included in this study, we found that AHI and ODI obtained from PAT tended to underestimate the degree of sleep apnea compared to PSG, whereas TST and MinO2sat by PAT tended to be slightly higher than PSG. Moreover, we demonstrated the relationship between W-AHI and P-AHI by performing linear regression analysis to generate the following equation: P-AHI = 1.09 (W-AHI) + 3.95.

By analyzing the ICC, we demonstrated that the agreement between PAT and PSG was excellent for AHI and ODI, good for MinO2sat, and fair for TST. We also found very good to excellent correlation between methods for ODI and moderate to good correlation for AHI, TST, and MinO2sat. Although ICC is the preferred statistical analysis tool for comparing 2 diagnostic devices, ICC in this study was influenced by high data variation. As a result, we made the decision to report both agreement and correlation.

Despite the promising outcomes in terms of agreement and correlation in several parameters in this study (especially AHI between PAT and PSG), the P-AHI was much higher than the W-AHI according to the equation obtained from linear regression analysis. This may be explained by...
the fact that we used a probe and an algorithm designed for adults. The use of an adult probe in children could result in the underdetection of respiratory events in the pediatric population. We included patients aged 8 to 15 years in this study because their fingers are large enough to accommodate the PAT probe, even though pediatric patients younger than 8 years may benefit more from PAT testing, since they tend to resist wearing electrodes and sensors of a traditional PSG.

We constructed ROC curves to identify the W-AHI cutoff points for diagnosis of severe OSA. A W-AHI value of ≥3.5 provided the highest diagnostic accuracy at 77.8%. When using a W-AHI value of 10 (the same as P-AHI criteria27), the specificity for diagnosing severe OSA was 91.3%. Since the specificity was high, patients with a W-AHI of ≥10 would have a high probability of having severe OSA. According to these findings, patients with a W-AHI ≥10 may be suitable for adenotonsillectomy.

Another study that investigated simultaneous comparative analysis of PAT and PSG in children was reported by Su et al28; however, their study was published in Chinese, with only limited data from their abstract available in English. They recruited 50 snoring patients aged 3 to 11 years. In the 6- to 11-year-old group, they only provided data comparing the OSA and non-OSA groups, which showed significant differences in many parameters, including the AHI, RDI, and sleep stages. In the 3- to 5-year-old group, they found significant difference between PAT and PSG in 6 patients with OSA. However, data relating to a correlation between PAT and PSG parameters were not presented in their abstract.

<p>| Table 4. Correlation Analysis between PSG and PAT. |</p>
<table>
<thead>
<tr>
<th>Parameters</th>
<th>r</th>
<th>95% CI</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHIa</td>
<td>0.64</td>
<td>0.30-0.85</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>REM-AHI</td>
<td>0.71</td>
<td>0.48-0.84</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>NREM-AHI</td>
<td>0.53</td>
<td>0.23-0.73</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>ODIa</td>
<td>0.83</td>
<td>0.67-0.90</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>TSTb</td>
<td>0.54</td>
<td>0.31-0.74</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>MinO₂satb</td>
<td>0.72</td>
<td>0.33-0.91</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Abbreviations: AHI, apnea hypopnea index; CI, confidence interval; MinO₂sat, minimum O₂ saturation; NREM, non–rapid eye movement; ODI, oxygen desaturation index; PAT, watch peripheral arterial tonometry; PSG, polysomnography; REM, rapid eye movement; TST, total sleep time.

aAHI and ODI were analyzed using the Spearman rank correlation coefficient.
bTST and MinO₂sat were analyzed using the Pearson correlation coefficient.

<p>| Table 5. Diagnostic Capability of PAT for Diagnosing Severe OSA (P-AHI ≥10). |</p>
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>W-AHI ≥3.5, %</th>
<th>W-AHI ≥10, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>76.9</td>
<td>46.2</td>
</tr>
<tr>
<td>Specificity</td>
<td>78.3</td>
<td>91.3</td>
</tr>
<tr>
<td>PPV</td>
<td>66.7</td>
<td>75.0</td>
</tr>
<tr>
<td>NPV</td>
<td>85.7</td>
<td>75.0</td>
</tr>
<tr>
<td>Accuracy</td>
<td>77.8</td>
<td>75.0</td>
</tr>
</tbody>
</table>

Abbreviations: NPV, negative predictive value; OSA, obstructive sleep apnea; PAT, watch peripheral arterial tonometry; P-AHI, apnea hypopnea index obtained from polysomnography; PPV, positive predictive value; W-AHI, apnea hypopnea index obtained from PAT.

Figure 4. Scatterplot of apnea hypopnea indices obtained from polysomnography (P-AHI) and watch peripheral arterial tonometry (W-AHI).

Figure 5. Receiver operating characteristic (ROC) curve for predicting severe obstructive sleep apnea (P-AHI ≥10) according to the apnea hypopnea index obtained from watch peripheral arterial tonometry (W-AHI). Area under the curve (AUC): 0.82 (95% confidence interval, 0.67-0.98; P < .001).
This present study has some mentionable potential limitations. First, we were not able to identify and include patients with a P-AHI less than 1. Second, the PAT probe used in this study was designed for adult fingers. Although we selected patients aged 8 to 15 years and sealed the probe to the finger using adhesive tape, it is possible that the probe may have loosened during testing. As such, the development of a pediatric probe and algorithm is needed to increase the validity and clinical application of PAT for diagnosis of pediatric OSA.

Conclusion
To our knowledge and based on our review of the English language literature, this is the first study to report the use of PAT for the diagnosis of OSA in children. There was good agreement and correlation between PSG and PAT data. A W-AHI cutoff value of 10 could detect severe OSA cases with high specificity compared with PSG. We suggest that PAT is another interesting diagnostic test for children with suspected OSA. A larger study with PAT designed for children, performed across all age ranges, and with a normal control group is needed.

Acknowledgments
The authors gratefully acknowledge Julaporn Pooliam of the Division of Clinical Epidemiology, Department of Health Research and Development, Faculty of Medicine Siriraj Hospital, Mahidol University for her assistance with sample size calculation and statistical analysis, and Jeerapa Kerdnoppakun of the Department of Otorhinolaryngology, Faculty of Medicine Siriraj Hospital for secretarial support.

Author Contributions
Archwin Tanphaichitr, conception and design, analysis and interpretation, drafting and critical revisions, final approval, agreement to be accountable for all aspects; Arathaya Thianboonsong, data acquisition, analysis and interpretation, drafting, final approval, agreement to be accountable for all aspects; Wish Banhiran, conception and design, analysis and interpretation, critical revisions, final approval, agreement to be accountable for all aspects; Vannipa Vathanophas, data acquisition, critical revisions, final approval, agreement to be accountable for all aspects; Kitirat Ungkanont, analysis and interpretation, critical revisions, final approval, agreement to be accountable for all aspects.

Disclosures
Competing interests: None.
Sponsorships: None.
Funding source: Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand. No role in study.

References